CHAPTER 1
Introduction

Abstract: This chapter describes the knowledge gap and outlines the research aim, objectives and questions that informed every stage of the socio-technical-systems (STS) conceptual framework and the integration thereof into the existing body of knowledge and highlights the novelty of the study. It presents the materials and methods used to achieve the objectives of the study. It explicitly explains the research gap in understanding and language between the concept of energy use and the notion of building physics to determine applicable retrofit interventions for upgrading the energy efficiency of residential buildings. In this chapter, information regarding the energy governance in EU-27 countries is presented to demonstrate the novelty of the retrofitting of high-density residential buildings in the South-eastern Mediterranean climate where the weather is subtropical (*Csa*) and partly semi-arid (*Bsh*). While many scholars have published works on upgrading the thermal performance of buildings in many aspects, including considering the occupants' habitual adaptive behaviour and thermal comfort, few have approached this topic from a time-limited, output-driven perspective of conducting a field survey through adopting the STS design approach. This chapter that comprises this handbook will guide the reader through a journey of research that inevitably leads to the key contributions in the field of applied sciences.

Keywords: Energy efficiency; Energy policy; Climate change; Occupant behaviour; Retrofit delivery; South-eastern Mediterranean

1.1 Energy Governance in Europe

With a growing world population that is characterised, in part, by an increasing number of people seeking to live in urban areas, achieving holistic sustainable behaviour poses numerous significant challenges (Government Office of Science, 2016a). Among these is overcoming the barriers that society itself poses—those of behavioural and social patterns that, in turn, drive energy consumption and resource use (Government Office of Science, 2016b). This is why the high density of residential developments and soaring land values in the South-eastern Mediterranean region, have prompted residents to maximise their liveable spaces by refurbishing their properties to increase living quality thus this attempt could result in improving indoor air quality and occupants' health and well-being. (Ozarisoy & Altan, 2017a). Hence, seeking to understand the problems caused by high land value and increases in energy consumption, resulting from the rapid increase in population growth and unplanned urbanism, has led to research on the adaptability of local construction practices in energy efficient retrofits (Ozarisoy & Altan, 2017b). In the South-eastern EU countries, the construction industry lacks strong drivers to implement energy efficiency regulations and technologies through building construction and retrofitting to fulfil a knowledge gap in the development of effective control mechanisms in retrofit policy design (Ozarisoy & Altan, 2018). Given this challenging context, reducing energy consumption of residential buildings—predominantly in terms of heating and cooling energy use—is of utmost importance for tackling with fuel poverty and climate change mitigation which have detrimental impact on building fabric thermal performance of post-war social housing stock in the EU-27 countries.

South-eastern Mediterranean Island of Cyprus has been facing a housing crisis for some time due to changes in its social housing construction practice policies in recent years (Alola & Alola, 2019; Ozarisoy & Altan, 2021a). After the social housing construction boom in the mid 1980s and early 1990s, government policies changed to meet the demands of its growing urban population—construction of both new housing and existing social housing development schemes were stopped and existing social housing estates were privatised over to construction companies (Ozarisoy & Altan, 2021b). This resulted in a significant decrease in available social housing, together with high private rental accommodations and unaffordable housing prices (Alola, 2020). Moreover, a recent government statistical report states that there is a need for 20,000 housing units to accommodate housing demands; however, they must also offer affordable housing schemes with liveable indoor conditions that consider people's well-being and health as well as the threat from climate change (Balkiz & Threse, 2014). Figure 1.1 demonstrates the universal design approach developed for this study.

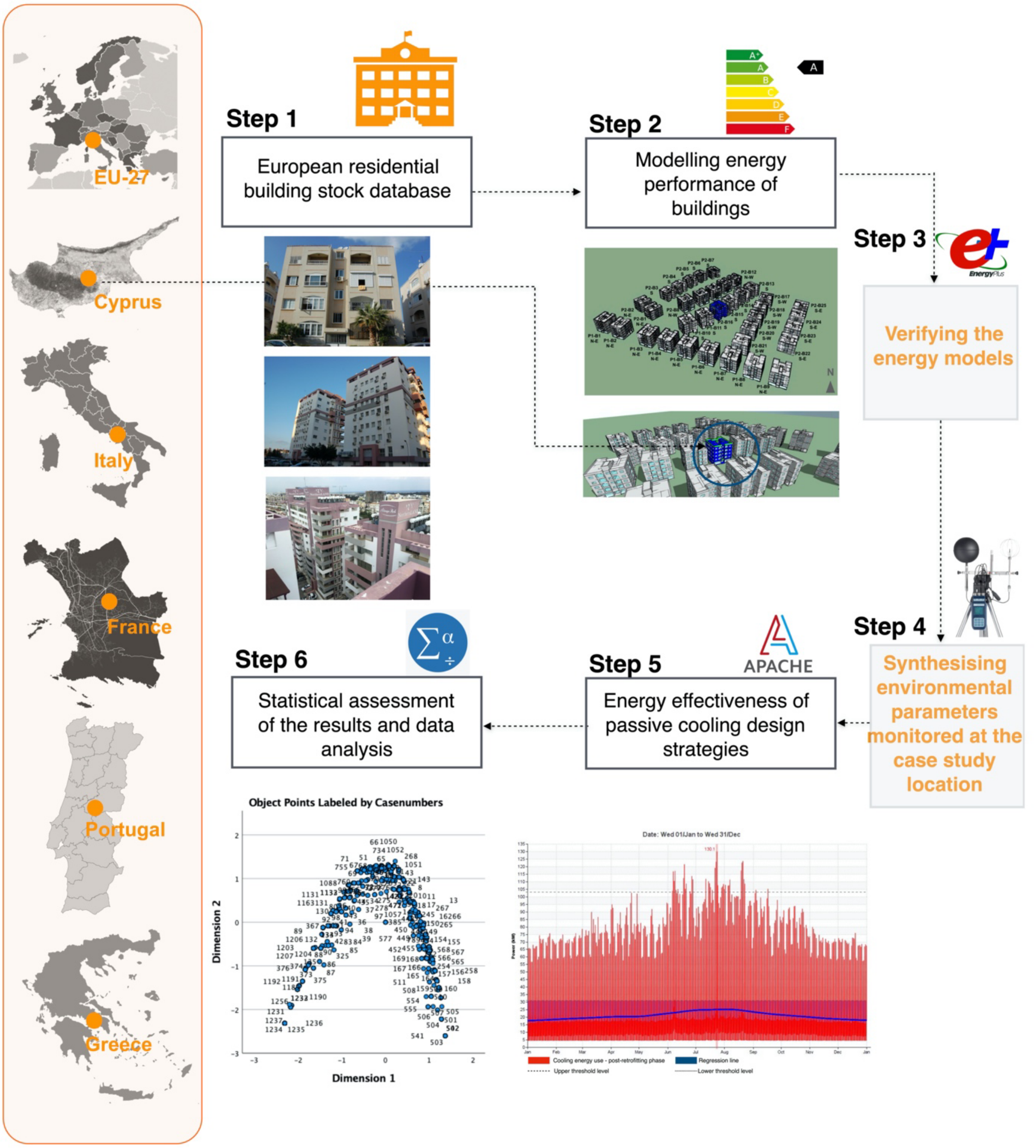

Fig.1.1 Contribution to the EU-27 energy policy framework.

In Cyprus, the construction sector is aware of problems with energy efficiency implementation (Çelik, Kamali, & Arayici, 2017; Ozarisoy & Altan, 2017a). It is also aware that, among the EU-27 member states in general, the implementation of regulations for the residential building sector lacks systemic retrofitting rules (Andaloro *et al*., 2010; Evcil & Vafaei, 2017). Thus, the practice of building such mass housing units continues without any control mechanism to implement the energy performance certificates (EPCs) in order to meet the objectives of the EU Horizon 2030 (Arbolino, Boffardi, & Ioppolo, 2019; Ozarisoy &

Altan, 2021b). The design and construction of new and rehabilitated residential buildings must be performed within climate change scenarios but without forgetting that they must also respond to the occupants' real-life experiences and focus on optimised thermally comfortable indoor air environment conditions throughout the year (Anderson *et al*., 2020; Heaviside *et al*., 2016; Ozarisoy & Altan, 2021a). Together with the increasing demands made on cooling services in the summer, more extreme events are predicted with which thermally poor performance residential buildings will need to deal in the future (Ballarini, Corgnati, & Corrado, 2014; Ballarini *et al*., 2017).

Consequently, passive cooling design strategies in summer conditions that do not imply additional energy consumption and further contribution to global warming must be prioritised (Ozarisoy & Altan, 2021c; Cristino, 2021). It is important to highlight the fact that indoor environmental conditions should be considered in relation to energy efficiency objectives that are in accord with the intergenerational occupants of residential buildings rather than with the state of the buildings (Cozza, Chambers, & Patel, 2020). At the same time, reducing energy consumption in residential buildings, particularly in relation to cooling, plays a principal role in achieving European environmental objectives for reducing the cooling energy demand that contributes to global warming (Dascalaki *et al*., 2016; Lowe & Chiu, 2020). Ultimately, the aim of this research is to understand the occupants' real-life experiences with energy use and the significant impact of the buildings' thermal properties on their occupants' thermal comfort, aiming to develop appropriately tailored approaches that support and maintain effective delivery of current and future policy initiatives for retrofit interventions in high density residential buildings.

This research examines the current cooling energy consumption patterns of base-case representative residential tower block developments (RTBs) in the South-eastern Mediterranean climate where the weather is subtropical (*Csa*) and partly semi-arid (*Bsh*); thus investigating the significance of their occupants' thermal comfort, seeking to provide further information about assessing domestic energy use in the residential sector. In order to do so, after setting up the research context, the validity of the nationally representative archetype housing stock in Cyprus and household population that were selected to develop bottom-up energy policy framework. A prototype RTB was developed to account for the dominant representative occupancy patterns gathered through a questionnaire survey to calibrate dynamic thermal simulations (DTS) for the building energy modelling and simulation. The study further investigates the occupants' neutral adaptive thermal comfort in conjunction with *on-site* environmental conditions measured at one point in time while concurrently conducting a questionnaire survey with social households. It also studies the impact of environmental conditions on both the occupants' thermal comfort and their actual domestic energy to develop evidence-based energy policy framework both in the South-eastern Mediterranean basin and central Europe.

As already stated above, in most cases of the situation currently in operation and with particular regard for the lack of control mechanisms in the retrofitting of high-density residential buildings, the occupants' adaptive thermal comfort and their thermal vulnerability to warming climate conditions should be considered due to the long-term heatwaves experienced during the summer period across the continental Europe. In fact, the importance of decision points has been stressed in energy efficiency standards and the expectations of occupants still focus on improving indoor quality, but the occupants' thermal comfort has been neglected by previous scholars while developing decision-making criteria for the development of retrofit design policy, which is worthy for an investigation in the field of applied sciences. Therefore, although the future is challenging, much attention must be paid to the efficiency of construction material, the perceived thermally acceptable comfort level and the energy use behaviour of occupants, instead of only being concerned with the systemic retrofit achieved using a holistic approach but without taking into account both warming climate conditions and the human-based approach in energy use.

1.2 Setting the Scene: Outlining energy efficiency objectives and energy demand scenarios

1.2.1 Aims and objectives

The aims of this research are to assess the domestic energy use in poor thermal performance of high-density residential buildings and their occupants' thermal comfort by considering the significant impact of overheating risk on energy consumption and occupants' thermal comfort and well-being, with the intention of forecasting of energy use to develop evidence-based retrofit design policy in EU-27 countries.

In particular, considering the cooling energy demand in the summer, using Famagusta's households as a case study. The study seeks to identify the impact of occupancy patterns and habitual adaptive behaviour of households on home energy performance in order to provide a basis for the information needed to calibrate building energy performance of targeted households. It also envisages to demonstrate that the occupants' real-life experiences with energy use have had a significant impact on calibrating domestic energy use to identify discrepancies between the actual and predicted energy use on the dynamic energy simulation platform simultaneously. Therefore, the sampling size is limited to Famagusta households only, due to technical limitations and time constraints, but this work could be generalised to the entire existing residential building stock and cover the entire post-war social housing stock.

The objectives are threefold. The first is to explore the factors that identify the households' socio-demographic characteristics, their knowledge of energy saving methods, the home energy systems they use and their summer and winter occupancy patterns, including window opening schedules and energy-efficiency awareness. The second objective is to investigate the overheating risk and the occupants' thermal comfort within representative RTBs in order to provide a basis for the building energy simulations. The third objective is to calibrate the energy performance of base-case representative prototype RTBs as a potential retrofit approach to the development of STS conceptual framework for optimising occupants' thermal comfort.

In order to highlight the importance of this pilot research project conducted in the South-eastern Mediterranean climate where the weather is subtropical (*Csa*) and partly semi-arid (*Bsh*), it is important to highlight that this project demonstrates a ground-breaking epistemological approach in two ways. First, it is the first pilot research project to investigate domestic energy use by considering the patterns of occupants and their real-life experiences with energy use in conjunction with assessing their thermal comfort by taking into account environmental parameters at the same time. Second, it also quantifies the impact of the buildings' thermal properties on the occupants' thermal comfort and the households' energy use, an area in which there is little research.

1.2.2 Highlighting issues on energy governance

EU governments have devised additional regulations and incentives to encourage the adoption of energy efficiency measures (EEMs) and systematically retrofitting of high-density residential buildings (European Commission, 2019b). Energy has become a significant issue in the EU; the resulting action plans reflect and highlight the importance thereof (Villca-Pozo & Gonzales-Bustos, 2019; von Platten *et al*., 2020). Current emergency plans are directed at entire communities and reveal the importance of energy conservation across Europe (Lowe & Chiu, 2020).

Tailoring the necessary information to reduce energy consumption according to specific requirements and characteristics of target household groups highlighted significant discrepancies between policies and the characteristics of building stocks that have been delineated in other studies, which investigated whether thermal upgrades were implemented according to official ordinances without considering the amount of energy described in various policy documents (Ballarini *et al*., 2017; Cozza *et al*., 2020; Szalay & Zöld, 2014). There are no strict policy measures or benchmarks for building energy performance in Cyprus, nor are there official plans to regulate holistic retrofitting schemes intended to improve energy efficiency. Cyprus has a legacy of low-quality building envelopes in the social-housing stock, which have accumulated over the last three decades due to ongoing unregulated construction practices and the absence of policymaking decisions to implement EPBD objectives (Ozarisoy & Altan, 2017a). The lack of planning in social-housing structure schemes also led to poor air quality and high thermal conductivity in the summer, which in turn caused overheating risks and thermally uncomfortable indoor environments (Mata, Kalagasidis, & Johnsson, 2018).

Another technical constraint is the lack of available primary databases to record the impact of EPCs on home-energy performance and household energy bills; this dearth of data is evident in many areas, such as legislation and regulations for issuing EPBDs and relevant training materials, which include the development of software tools and an online open-source platform to disseminate the outcomes of each country (Ballarini *et al*., 2014; Cozza *et al*., 2020). In this regard, there is a growing body of the literature that recognises the importance of the integration of EU mandates, because the representativeness of housing stock in the South-eastern Mediterranean region was not thoroughly classified, primarily because the housing typology classification was based on a random selection of case-study buildings for an archetype analysis of local initiatives and energy agencies (Baldoni *et al*., 2019; Berrardi, 2017; Ozarisoy & Altan, 2021b). Because of this challenge, a comprehensive energy-performance evaluation of housing stock can only be conducted at the building-level; as such, there is an urgent need for effective nationwide implementation of EPCs and other control mechanisms to achieve policy targets and additional actions related to future holistic retrofitting efforts for urban neighbourhoods, all of which must put into place by stakeholders and government initiatives in the EU-72 countries. To fulfil knowledge gap in energy-policy framework and retrofitting of existing housing stock, the main research question formulated for this study is as follows:

Main research question (***RQ***): In what ways and to what extent can energy performance of post-war residential buildings in the South-eastern Mediterranean Island of Cyprus be evaluated using their occupants' real-life experiences with energy use and how can the cooling consumption demand in the summer be reduced?

In order to answer the main research question, the following three key research sub-questions were also formulated:

- ***RQ-1:*** How important are the 'occupants' socio-demographic characteristics' and 'actual energy use patterns' to calibrate the discrepancies between the actual and predicted energy use? At what stage could determinant factors affect the implementation of retrofit interventions into the energy policy decision-making process?

- ***RQ-2:*** What are the main determinants of 'energy use' in residential tower blocks and to what extent do retrofitting options have the potential to achieve optimum indoor comfort conditions?

- ***RQ-3:*** Using a base-case scenario, how can thermal properties of buildings affect their occupants' thermal comfort in an RTB building prototype that is part of a post-war social housing estate?

The study focuses on socio-cultural issues deemed to be the most relevant to efforts to improve the thermal efficiency of residential buildings; a number of significant, difficult-to-quantify home-energy-performance factors that are often under emphasised in energy policy, such as the ingrained energy-use habits of different households and the socio-demographic characteristics and degree of thermal discomfort thereof, can facilitate the development and implementation of energy-efficiency schemes, which is why an STS approach that simultaneously considers multiple factors is an effective means to address the EEG. In line with this objective, this empirical study adopts an STS conceptual framework that concurrently considers retrofitting-related social and technical factors to improve the likelihood of adopting long-term holistic retrofitting schemes that will enhance the energy performance of the domestic built environment.

1.2.3 Energy policy gap

Efforts to retrofit buildings and upgrade the thermal efficiency of existing housing stock are gaining momentum due to the Energy Performance Buildings Directives (EPBD) mandates, which require that the domestic built environment in European Union (EU) member states cut CO_2 emissions, reduce national energy demands and improve building performances (Berger & Höltl, 2019; Bergman & Foxton, 2020; Fokaides *et al.*, 2017). The hypothesis presented here is that a series of difficult-to-quantify home energy performance factors have not been thoroughly considered, especially those of the occupants' socio-demographic characteristics and their real-life experiences with energy use, which could establish a novel research design approach in building retrofitting. There exists a wealth of retrofit interventions for more effective policy delivery that need to be methodically planned and carefully put into action. To fill the energy-efficiency gap, improvement in the physical quality of housing stock is directly related to human-based factors and therefore led us to develop a novel methodological framework for domestic-energy use.

One of the main goals of this empirical study was to encourage social-housing occupants to assess and adopt principles of retrofitting design policies to improve the extant mass-housing stock and bring them into effect. This approach will investigate buildings that were built under the governmental social-housing scheme, which have not yet undergone any refurbishments to make the structures more energy efficient and adaptable to the local environment. This endeavour was prompted by an understanding that the current planning policies have been ineffective when taking the energy consumption of the existing housing stock, including that of mass-housing estates built during the property boom in Cyprus, into consideration. The outcomes of this empirical study revealed an urgent need for governmental bodies to devise effective policies for the mass-housing sector so the construction industry will apply necessary retrofitting strategies on a rapid and large-scale basis to reduce energy consumption.

In the South-eastern Mediterranean basin, no existing research was identified that applies energy efficiency standards of retrofitting to any building types, whether large-scale social housing developments or otherwise. The initial pilot field survey study attempted to ascertain what household members identified to be energy inefficient uses of their cooling systems and how they adapted these cooling systems for their thermal comfort in changing climate conditions, particularly in the hottest summer month—August. This helped build the picture of occupancy that reflects on the households' resultant energy use in order to compare and validate energy consumption in the building modelling simulation.

1.3 Conceptual Framework

This research primarily assessed the domestic energy use of households and investigated their occupants' thermal comfort in low-quality building fabric of the RTBs in order to find the information necessary for subsequently calibrating building energy performance, aiming to provide guidelines, tools and policy implications for improving energy efficiency of high-density residential buildings in the South-eastern Mediterranean climate where the weather is subtropical (*Csa)* and partly semi-arid (*Bsh*). To ensure systematic analysis of the key aims and objectives, a mixed methods research design was adopted that predominantly sits on the grounds of the quantitative research approach for developing an evidence-based energy-policy framework to assess robust energy-performance evaluation and certification schemes in Europe. Figure 1.2 delineates the step-by-step development of conceptual framework to bridging energy performance gap of a social housing stock in the South-eastern Mediterranean Europe.

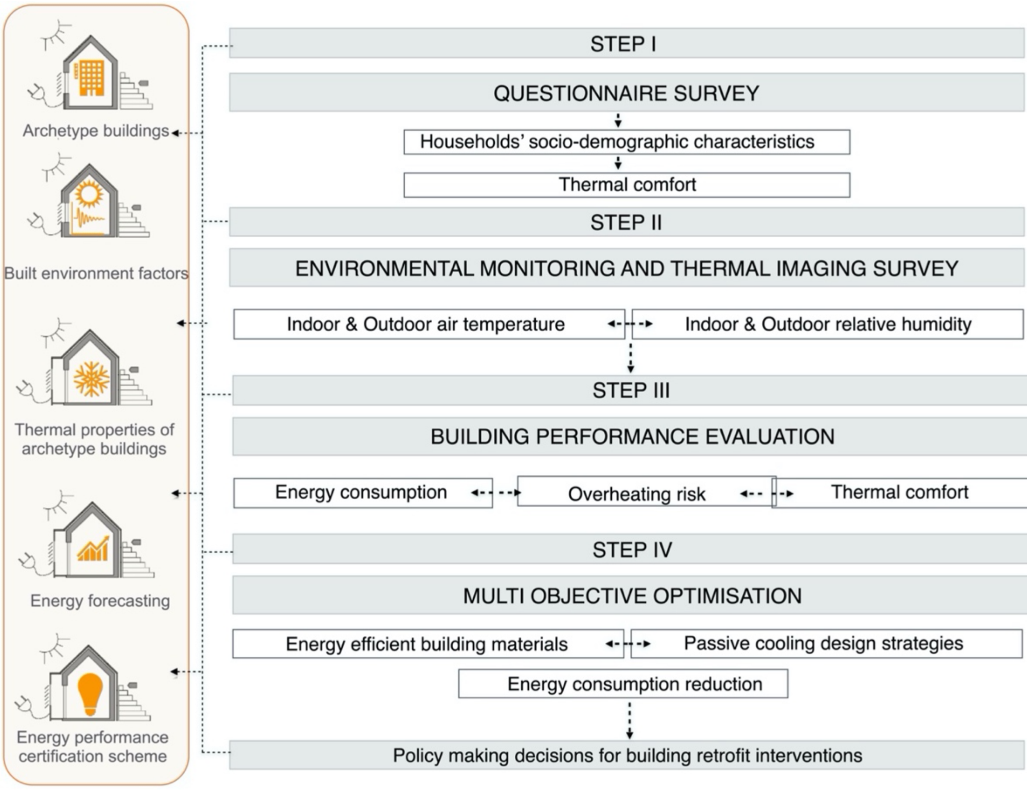

Fig.1.2 The stages of developing an evidence-based energy policy framework.

The study used an exploratory case study approach to carry out analysis on the nationally representative of the post-war social housing estate in multi-family apartment units which were built between the mid 1980s and early 1990s under the government's social housing scheme in Cyprus. This approach helped provide a good representation of the common drivers in the property market by considering different levels of retrofit design interventions to promote the challenges that come from taking into account the fact that the occupants' energy use behaviour and the thermal properties of the buildings investigated have a significant impact on the occupants' thermal comfort and the actual energy use in post-war social housing estates.

The adopted mixed methods research design used a questionnaire survey that was designed with the intent to capture the essential data for the post-war social housing stock by incorporating high level building parameters and occupant energy use, respectively. This empirical study evaluated the current energy performance of base-case representative prototype RTBs by embedding building energy performance modelling and simulation methods. It investigated the significance of the patterns in energy use of the occupants to calibrate the energy performance of retrofit RTBs' cooling energy demand and the occupants' thermal comfort during the long-lasting heatwaves recorded across continental Europe in the summer of 2018. Furthermore, the study elaborated on the significance of dominant representative occupancy patterns embedded into building simulation parameters to calibrate the actual energy end-use of a prototype RTB, as a base-case scenario development, in order to provide representative energy use data to improve building energy efficiency using the questionnaire survey and simulation data. As an outcome of evaluating the energy performance of the reference buildings under investigation, the performance of a case study building was modelled and simulated in the tradition of the socio-technical-systems (STS) approach in building physics.

1.3.1 Socio-technical-systems approach

An STS approach was used as a theoretical framework to integrate household socio-demographic characteristics related to energy use, the thermal-conductivity level of buildings and environmental factors; and to address the question of how different contexts influence the development of energy-efficiency strategies. Drawing on this approach, this empirical study investigated domestic-energy use and indications of how much is being used thereof in base-case RTBs to improve the energy efficiency of existing social-housing stock. A mixed-method approach was used: Quantitative survey data provided information regarding the taxonomy of housing-stock data, and semi-structured interviews were conducted to better understand the socio-demographic characteristics, energy use and thermal comfort that elicited participant views related to the development of energy performance certification (EPCs) schemes. The STS model was utilised to develop an evidence-based energy-policy framework that would consider household socio-demographic characteristics, occupancy patterns and the impact thereof on home-energy performance to empirically represent the EEG. The use of this methodology provided the necessary groundwork to develop a hypothesis for an effective bottom-up policy-design approach. In this study, the hypothesis was to examine household socio-demographic characteristics in actual energy use to explore associations between energy use and building-envelope thermal performances by collecting *in-vivo* primary data and conducting an analysis thereon.

It should be noted that the t study focuses on the STS research design approach to integrate a multidisciplinary study into a methodology for building-optimisation studies. The choice of focus was intentional in light of the fact that decisions associated with post-war social-housing development estates, which seek to improve the energy efficiency of existing housing stock were generally made according to assumptions, overlay general studies or forecasting scenarios that fail to consider human-based factors in building-energy modelling (BEM) stage. Energy-efficiency policy implications, on the other hand, were driven by environmental agendas that aim to reduce CO_2 emissions. Such policies typically consider energy-security issues coupled with the integration of energy-efficient building materials and systems during the retrofitting stage, but they fundamentally serve CO_2-emission-reduction goals to achieve the EU mandates by 2030.

After the proposed methodological design approach is developed in the most accurate manner possible, the conclusions for the study will serve as an effective policy- and decision-making tool in the area of domestic-energy use. The implications of the study were exploratory in nature and used a human-based empirical design approach that specifically targeted household energy-use characteristics, the overheating risk of different occupied spaces and the impact thereof on occupant thermal comfort. To fulfil the study research, aim and objectives, the conceptual framework placed social-household occupants at the centre who were influenced by three determinant factors—socio-demographic characteristics, environmental conditions and building thermal properties—as shown in Figure 1.3.

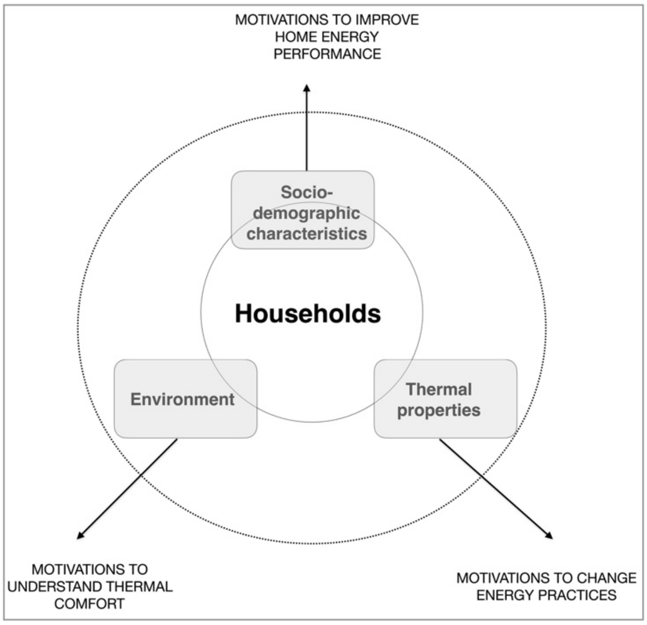

Fig.1.3 The socio-technical-systems approach for developing an evidence-based energy-policy framework within the integration of the Energy Performance of Buildings Directives (EPBD).

This model illustrates the manner in which the STS conceptual framework can be adopted to address EEG, as opposed to measures that simply targeted Famagusta households. Without considering the significance of occupancy patterns on energy use, the empirical studies aim to address vulnerable neighbourhoods steeped in energy poverty may not be as effective (Berger & Höltl, 2019; Franke & Nadler, 2019; Gaspar, 2017).

The STS model clearly demonstrates that without an understanding of household socio-demographic characteristics, empirical studies conducted to develop the potentialities of the STS approach has found to be that an appropriate method of design to overcome issues in the EEG (Cockbill *et al*., 2020; Guerra-Santin *et al*., 2017). As such, the variants in the model are interlinked (i.e., the inner circle), and they affect home-energy performance (i.e., the outward-moving arrows and dashed outer circle).

By investigating the factors that were outlined in the model, all obtained data were concurrently analysed in a feed-forward fashion, then embedded into each other to inform policymaking decisions related to energy use (Sovacool *et al*., 2020). The STS approach can be found in previous scholars' work in central European countries and few studies that considered council estates in the U.K., but no other studies adopted the STS and investigated household energy use, occupancy patterns and their degree of thermal discomfort in the south-eastern Mediterranean Europe have been considered (Anderson *et al*., 2020; Johnstone *et al*., 2020; Ozarisoy & Altan, 2021a). Hence, this empirical study is the first to examine the applicability of the STS approach while taking household cultural values, norms and social assets into account.

1.3.2 Questionnaire survey

This research adopted a methodology that included questionnaire surveys distributed in high-rise prototype RTBs with different orientations, investigating whether flat floor level differences have a substantial impact on the energy use of households at a post-war social housing estate in the South-eastern Mediterranean climate of Cyprus. A thorough review of the study was conducted, including several instances of feedback obtained during the pilot study. The methodology was then calibrated to check the accuracy and reliability of results obtained through semi-structured interviews conducted with social households in the form of both close-ended and open-ended discussions with the residents of 36 RTBs in this social housing estate. Figure 1.4 demonstrates the development of the questionnaire survey and sampling procedure for the field study investigation.

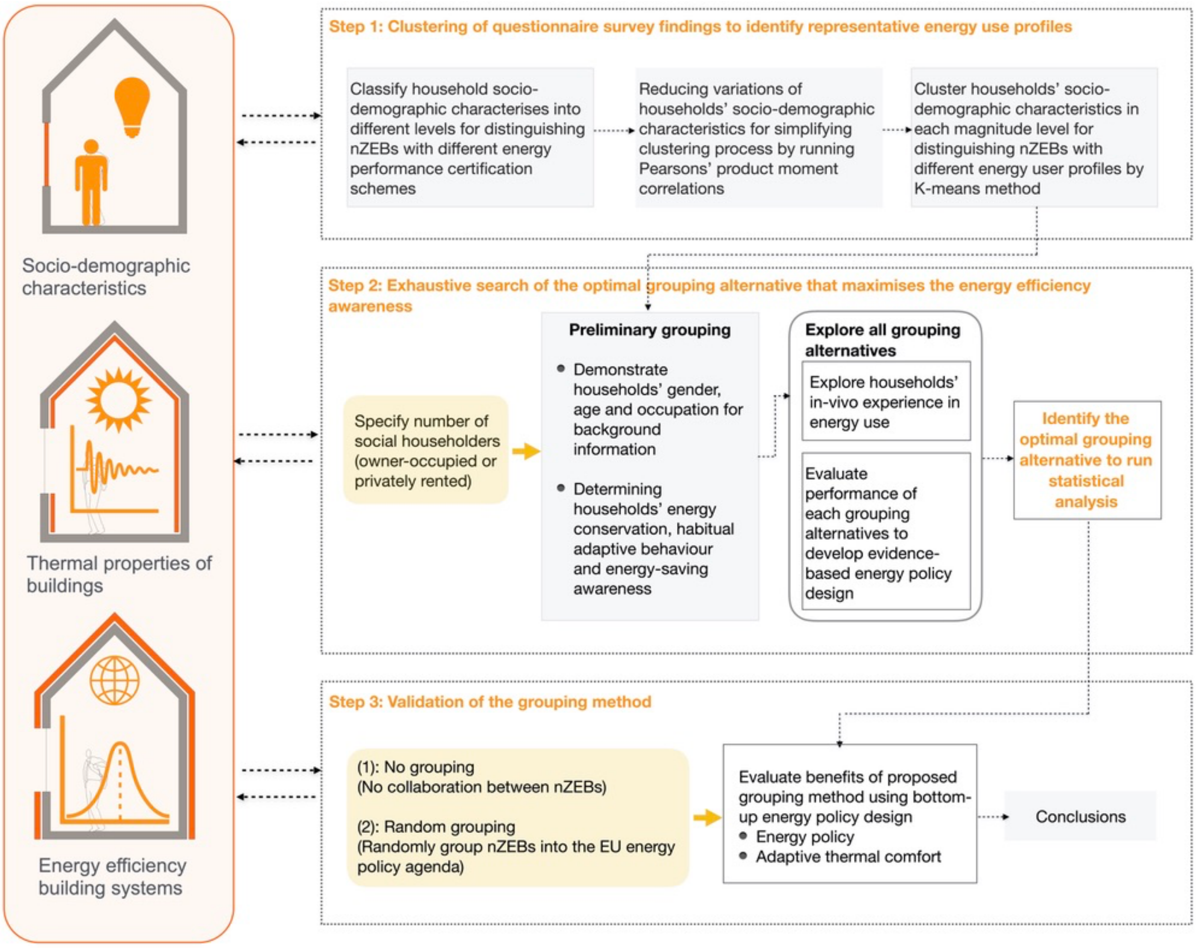

Fig.1.4 Three key research areas selected for the development of the questionnaire survey.

To collect subjective data from the building occupants about domestic cooling energy use and to evaluate their degree of thermal discomfort in specified orientations, a standardised questionnaire survey was developed. The survey was conducted with members of 118 households between July 28, 2018 and September 3, 2018. The questionnaire included 28 questions, adopting a combination of open-ended, partially closed-ended and predominantly closed-ended questioning approaches. It was designed to obtain predominantly quantitative feedback from respondents, using quota sampling to generate a nationally representative sample of Cyprus's households. Quota sampling typically involves issuing interviewers with a set of quota characteristics (in this case, tenure type, orientation, different floor level and occupancy patterns on energy use) and a corresponding number of interviews to be achieved in each characteristic category to develop evidence-based energy policy framework. The survey aimed to obtain a representative sample by reflecting the demographic make-up of the households in which interviews were given.

A total of 200 households from 288 flats were randomly selected, covering the post-war social housing stock within other municipalities in Cyprus to demonstrate the nationally representativeness of housing stock and population sample selected for the empirical study. Household selection criteria were stratified by the State Planning Organisation–Cyprus and a household-level socio-economic indicator—the social grade of household reference person. Sampling units were selected in proportion to the numbers of households within each post-war social housing estate within eight cities in order to generalise the findings while developing effective EPC schemes in this particular region.

The sample was based upon the household rather than individual characteristics because the primary aim was to collect data from individual respondents as it relates to their household. For this reason and to avoid selection bias regarding knowledge of energy use in the household, there was no systematic respondent selection within the selected households with respect to energy use—e.g. who pays the energy bills, who makes more energy decisions or who spends most time at home. Interviewers were asked to interview anyone over 18 years of age living at the address without selecting (or encouraging self-selection) on the basis of how the household members saw their role in relation to energy (although this role was recorded during the interview).

Correlations among multiple socio-techno-economic parameters were collected from the questionnaire surveys to investigate the relationship among households' socio-demographic parameters using version 25.0 of the Statistical Package for the Social Sciences (SPSS) software suite. The SPSS software suite was chosen for analysing significant parameters gathered thorough a questionnaire survey because it enables another novel methodological approach to contribute by validating survey findings in conjunction with dynamic thermal simulations concurrently.

First, descriptive analysis was used for the interview findings to report on the energy use behaviour of occupants, followed by correlation analysis methods applied to the findings to evaluate the correlation between different parameters. In addition, the Predicted Mean Vote (PMV) sensitivity index was calculated using the standardised rank regression coefficient. In this study, the sensitivity index indicated the degree of influence of different variables on the PMV and the sign (+ or –) of the sensitivity index on the Likert scale indicated the correlation between the dependent and independent variables to investigate the 'neutral' adaptive thermal comfort thresholds for the multi-family housing (MFH) units in the South-eastern Mediterranean climate.

Considering the overheating risk experienced in base-case nationally representative RTBs, thermal comfort surveys were conducted in the living rooms of the households to assess the occupants' thermal comfort level with the environmental conditions recorded at the time of the survey. Indoor environmental measurements of operative temperature (OT) and relative humidity (RH) were taken during the face-to-face questionnaire survey using the portable Extech HT200 heat stress wet bulb globe temperature meter instrument. The questionnaire included questions about the general perception of environmental conditions (including operative temperature and relative humidity), frequency of heating and cooling systems used, window opening schedules and details about the length of the households' residency, including details of space heating and cooling systems at home.

For the assessment of thermal comfort at the time of the questionnaire, the 7-point American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) – ASHRAE standard-55 thermal sensation scale was used (ASHRAE, 2017). In parallel with the questionnaire survey, *on-site* environmental monitoring and *in-situ* measurements, subject respondents' clothing levels (*clo*) and their reported metabolic activity (*met*) levels for the 20 minutes prior to the questionnaire were also recorded to integrate households' in-vivo experience in the building energy modelling to calibrate households' energy use and identify the regression forecasting of 'neutral' adaptive thermal comfort thresholds in the South-eastern Mediterranean climate.

1.3.3 Environmental monitoring

The outdoor air temperature and relative humidity (RH) levels of the environmental conditions were monitored between July 28 and September 3, 2018 to assess the overheating risk issues of the flats interviewed in the South-eastern Mediterranean climate where the weather is subtropical (*Csa*) and partly semi-arid (*Bsh*). This monitoring duration overlapped with the 2018 heatwave period – which was hit the continental Europe. In the summer of 2018, the Meteorological Office of Cyprus recorded the highest temperatures across Europe since 1976 – the highest outdoor air temperature was recorded at 43°C. The outdoor environmental conditions, including the operative air temperature, relative humidity and heat stress index, were monitored by a Wireless Vintage Pro 2 weather station from Davis Instruments at the case study location. The monitoring of outdoor air temperature and relative humidity (RH) levels were recorded in the post-war social housing estate where is in the coastal city of Famagusta, Cyprus. Figure 1.5 demonstrates the field study investigation procedure to develop 'neutral' adaptive thermal comfort.

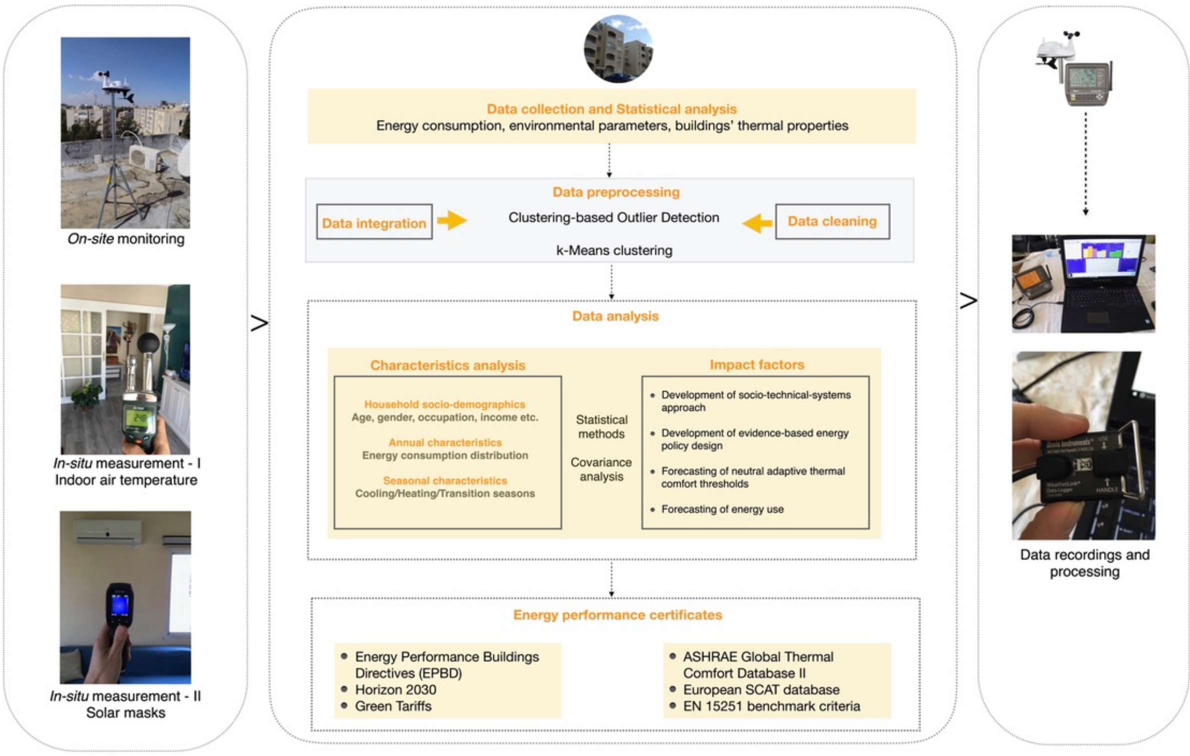

Fig.1.5 Environmental monitoring of European buildings.

The indoor air temperature was recorded using a thermometer (resolution 0.1°C), the globe temperature was recorded using a globe thermometer, which is a 15 cm diameter thin-walled copper sphere painted black (resolution 0.1°C), the relative humidity (RH) was recorded using the Heat Stress WBGT Meter model HT200 by Extech Instruments (resolution 0.1°C) and the black globe temperature (GT) was recorded. In order to validate these findings, additional *in-situ* measurements were carried out using a forward-looking infrared radiometer (FLIR) infrared thermographic camera to assess the occupants' decisions on thermal comfort preference votes (TPVs) and thermal sensation votes (TSVs) consecutively.

1.3.4 Building energy simulation

The Integrated Environmental Solutions (IES) software suite version IES 2021.1.0.0 was used to assess building-fabric thermal performance of base-case RTBs and validate the longitudinal field study investigation findings for the development of 'neutral' adaptive thermal comfort as benchmarking criterion. The scope of the simulations was based on the indoor air temperature in relation to the thermal comfort temperature of each selected occupied space in representative apartment units in the post-war social housing estate as base case scenario development in retrofit policy design. In this empirical study, both the analytical energy modelling and dynamic thermal simulations were used to assess the current energy performance of the social households that were interviewed at the time that the longitudinal field survey was conducted. A south-facing RTB was chosen as the base-case representative building to reduce the timely process of performing dynamic thermal simulations and numerical calculations in the IES software suite. To increase the credibility of energy simulations, dominant representative occupancy patterns were identified through a questionnaire survey and corroborated into the building energy simulation model. Figure 1.6 illustrates the building energy simulation procedure developed for the energy forecasting analysis of archetype RTBs.

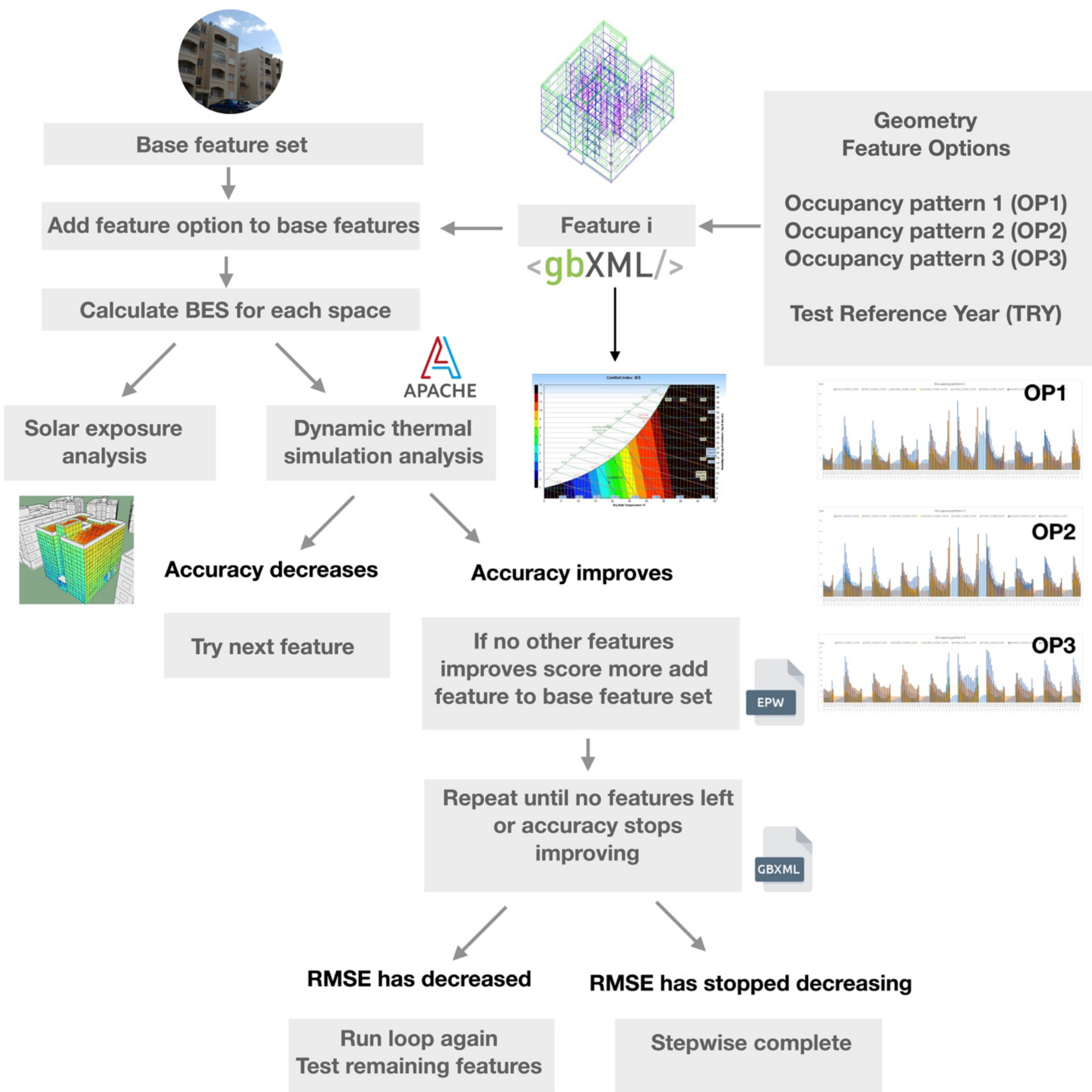

Fig.1.6 Inquiry strategy of DTS analysis using the ApacheSIM software interface.

The IES simulation tool was selected as the building modelling simulation software because of its sufficient validity for calculating the DTS analysis, indoor air temperature and relative humidity (RH) in each occupied space at home, which it performed accurately in nearly all the cases analysed with an hour interval per DTS calculations. Specifically, the Thermal Comfort software interface of the IES suite is the application that measured the 'adaptive comfort' of the representative base-case RTBs. When this interface is also considered in combination with the DTS components of the IES, it is possible to concurrently assess the energy performance of material changes while testing energy effectiveness of retrofit design interventions developed for the study.

To assess the energy performance of the prototype RTB in this empirical study, thermal templates were constructed in the IES ApacheSim software interface. These templates defined the space conditioning systems (Apache Systems) and gained variation profiles for each occupied zone within the building. The energy performance of the sample rooms was investigated by developing black-box analytical energy models in a well-established suite of the IES software suite, which includes ModelIT, SunCast, Apache, MacroFlo and VistaPro applications to develop a visual guidance while developing retrofit design interventions.

The regression forecasting of energy use and building-fabric thermal performance of the prototype RTBs and the overheating potential were simulated between May and September 2018 in order to demonstrate the worst-case scenario to understand the impact of climate change and develop mitigation strategies. To validate the data from the questionnaire, the thermal comfort surveys and the *on-site* environmental monitoring, the base-case representative MFHs were investigated in line with the gathered data from the field survey embedded into the building energy simulation, bringing more reliable findings on the current energy consumption and overheating risk of European residential buildings.

The calibration of the current energy performance of existing housing stock implies plenty of parameters and variants which consists of complex nature of occupant behaviour in energy modelling. This empirical analysis presented that the resultant energy comes from the complex interaction of the climatic variables, the building type, its physical form, architectural design principles, occupancy profiles, building construction systems and the type of domestic cooling appliances used by households. This research covers a broad spectrum of complex parameters – socio-technical-systems, focusing on the impact that some of these could have on the energy consumption and the occupants' thermal comfort in policymaking decisions on retrofit interventions.

One of the most important reason for adopting the DTS was to produce a mathematical model or data series that would help the architects, building engineers and designers in the early stages of planning energy effective retrofit design strategies to predict, with a tolerable margin of error, this epistemological approach underpinning that a building is going to demonstrate human based interactions on energy use, thus being able to quantify its future impact on the built environment.

1.4 Retrofit Strategies and Energy policy design initiatives in Europe

1.4.1 Retrofitting the EU domestic built environment

Many scholarly pilot research projects have investigated the interplays between the government policy on thermal retrofit and the current energy efficiency awareness in energy use of residential buildings at which the policy was aimed, focusing on EU-27 countries. As previously stated in section 1.1, one of the main concerns is that the South-eastern Mediterranean Island of Cyprus is burdened with a legacy of low-quality of the post-war social housing stock (Attia *et al*., 2017; Fokaides, Polycarpou, & Kalogirou, 2017; Ozarisoy & Altan, 2017a). There are no measures or benchmarks for building energy performance nor official roadmaps for regulating 'retrofit interventions' to address energy efficiency in the residential sector (Evcil, 2012; Ozarisoy & Altan, 2021a; Savvides, 2017).

Previous research has indicated that there is a lack of policy initiatives and implications in understanding the importance of energy use (Hardy & Glew, 2019). According to Hamborg et al. (2017), one strategy for putting this thermal deficiency of buildings is understanding the variance in energy performance in terms of the gap between the design and the construction process. One prevailing opinion here is to transcend the benefits of implementing energy efficiency systems into building's retrofitting (Annibaldi *et al*., 2019). This study also broadens it to a much wider perspective concerning energy use of existing post-war social housing stock, including accounting for the importance of the occupants' thermal comfort to fulfil a knowledge gap in households' habitual adaptive behaviour on energy use.

This research intends to propose a novel methodological approach for using the occupants' real-life experiences with energy use and longitudinal field study investigation to predict the cooling energy demand, the overall energy consumption and to optimise the occupants' thermal comfort, taking nationally representative low-, medium- and high- rise RTBs asas a base-case scenario development for the building energy simulations. To fulfil research aim and objectives, it is considered that this approach is compelling for the following reasons. First, Cyprus is an Eastern Mediterranean Island that is experiencing a profound transformation in the construction industry (Pulhan *et al*., 2020; Ozarisoy & Altan, 2017a; Safakli, 2011). As a consequence of rapid urbanisation, high-speed large-scale construction projects are ongoing, predominantly in the residential sector (Tselika, 2019). Furthermore, the legislative framework lacks policymaking and implementation procurement for upgrading the thermal efficacy of those housing stock in both existing and newly built residential buildings due to its geopolitical position in the Mediterranean Sea (Varoglu, Temel, & Yilmaz, 2018). Nevertheless, in Southern and Central European countries, the legislative framework for energy efficiency has been remarkably strengthened over the last few years, regardless of a lack of knowledge about the technical implementation of energy efficient retrofit strategies while considering different climatic conditions and building regulations in decision-making processes (Bertoldi & Mosconi, 2020).

In Cyprus (an EU member state) and Northern Cyprus (a non-EU member state), government initiatives have made attempts to tackle the burden of existing housing stock by changing the legislative framework for adopting the Energy Performance Buildings of Directives (EPBD) guidelines and net zero energy building schemes to upgrade the thermal efficiency of existing building stocks (Boccalatte *et al*., 2020; Ozarisoy & Altan, 2021a). This indicates that such legislative frameworks were not devised by taking into consideration the occupants' habitual adaptive energy use behaviour, which could provide effective guidelines to reduce energy consumption and optimise occupants' thermal comfort concurrently in the residential sector even though they are not yet mandatory (Buessler, Badariotti, & Weber, 2017; Kyprianou *et al*., 2019).

Additionally, the government of the Republic of Cyprus (RoC) has promoted a multilateral agreement with the objective of implementing energy efficient buildings systems in retrofit interventions to improve the efficiency of existing housing stock (Panayiotou *et al*., 2013; Serghides *et al*., 2015). This transformation technology and its technical legislation procurement, and know-how about how to implement energy efficiency policies, in particular with regard to the European International Organisation for Standardisation (EU-ISO) calculation benchmarking legislation and energy-rating systems. Given this context, the philosophical underpinning of this research could assist the transformation into energy efficient and optimised occupants' thermal comfort for policymaking decisions in domestic energy use.

As previously stated, the study attempts to identify key features from policy instruments and retrofitting initiatives across EU-27 member states, which could improve the possibility of reducing energy consumption and optimise the thermal comfort level of occupants within the housing sector in the South-eastern Mediterranean region. This study implies the importance of adopting comprehensive, interdisciplinary collaboration to examine and test the energy performance of base-case representative residential tower blocks (RTBs) for appropriately making energy efficient retrofit interventions to improve the energy performance of buildings and their occupants' thermal comfort.

1.4.2 Retrofit technology and energy efficiency behaviour preferences

Some current and previous research has been conducted on ensuring indoor comfort conditions and predicting comfort levels of rooms in line with the reference of the European BS EN 15251-Indoor environmental input parameters for design and assessment of the energy performance of buildings—addressing indoor air quality, thermal environment, lighting and acoustics (Ozarisoy & Altan, 2021a; Semple & Jenkins, 2020; Serghides, Dimitriou, & Katafygiotou, 2016). Considerable literature has been published that evaluates the assessment methods for the performance of unconditioned residential buildings in the summer period (Szalay & Zöld, 2014; O'Sullivan & Chisholm, 2020).

What we know about optimising the occupants' thermal comfort is based primarily upon empirical studies that investigate the overheating risk for indoor spaces in the face of climate change, where an increase in temperature and a higher frequency of extreme weather events, such as heatwaves, is expected (Fokaides *et al*., 2016). Several studies have also documented a lack of benchmarking between set input parameters and occupant behaviour so that the occupants' thermal comfort can be measured and the risks of building overheating can be assessed (Feng *et al*., 2019; Fernández-Agüera *et al*., 2019).

Recently, researchers have shown increased interest in assessing the calculation of both the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indices, together with information for estimating certain localised effects, such as shading and natural ventilation (Fawcett & Hampton, 2020; Ozarisoy & Altan, 2021a). However, the (CIBSE) TM52 Overheating Task Force has noted that a new approach to defining overheating in terms of the occupants' thermal comfort and well-being is needed, particularly for residential buildings without mechanical cooling. This approach follows the methodology and recommendations of EN 15251 to determine whether an existing occupied residential building can be classified as being in danger of becoming overheated, particularly in the summer. Changing climate, in addition to increasing population and rapid urbanisation, presents a need for cities to adapt to new conditions and develop resilience in order to provide thermal comfort to occupants (Florio & Teissier, 2015; Barone *et al*., 2019).

In response to this new need, this study's questionnaire survey—targeted at a post-war social housing estate in the coastal city of Famagusta—was designed and conducted. One of its main intentions was to map the occupants' thermal comfort within this geographic domain, together with *on-site* monitoring of the weather conditions and concurrently *in-situ* measuring the indoor environmental conditions of the interviewed flats in 36 RTBs which were selected an archetype building for building energy modelling. Additionally, questions about the occupants' energy use patterns, window-opening schedules and types of cooling devices used were combined in this survey, which was conducted during the peak cooling demand period in August 2018.

A wealth of data was collected and analysed, seeking to uncover significant correlations between the occupants' energy use patterns and how information is communicated and disseminated to support the implementation of retrofit interventions. At the same time, a thermal imaging survey was conducted at each RTB for both the summer and winter periods in order to better understand the heat losses through the buildings' envelopes and to assess the overheating risk of post-war social housing stock.

To assess cooling energy use and households' degree of thermal discomfort, conditions in base-case nationally representative RTBs, with high retrofit potential, were selected to develop an evidence-based energy-performance evaluation and certification schemes; thus, providing a subsequent information to calibrate the discrepancies between the households' actual and predicted energy use in line with assessing their thermal comfort.

The outcome of building performance evaluation for these households and, in particular, the building typology investigated could establish the grounds for the applicability of energy efficient and cost-effective retrofit interventions in purpose-built post-war social housing stock, which have shown similar climatic characteristics and building regulations—although this approach could be expanded to other EU-27 countries in terms of the methodology developed in this empirical study. In general, the overarching aim of the study is to contribute to the improvement of the occupants' thermal comfort, together with reducing domestic energy use as well as the economy, efficiency and effectiveness of the existing residential building stock to achieve their social objectives in the field of applied sciences.

1.4.3 Development of evidence-based methodological framework for retrofit delivery

The originality of the research presented in this handbook lies in its epistemological approach of adopting a mixed methods design to capture and solve the complex problem relating to demonstrating a roadmap of the future profiles of household energy consumption and optimising the occupants' thermal comfort by providing a policy advice tool for the policymakers. This is an attempt to meet the net zero energy scheme targets, as enshrined in the Energy Performance of Buildings Directives by 2030 and the Climate Change Act of 2050. Consequently, the research effort within this book has made a number of contributions to the existing body of knowledge. Its unique contribution is the development of a model that incorporates socio-technical issues that can be used for decision-making in domestic energy use. Other contributions are highlighted below:

- The research presents the first building energy simulation modelling efforts applied to a representative post-war social housing stock in Cyprus in order to build up an exemplar model household energy consumption and occupants' real-life experiences with energy use through a questionnaire survey based on the complex socio-technical interactions influenced by both dependent and independent variables collected from the households.

- The analytical energy model developed, especially its conceptual-model-system thinking aspect, is capable of providing a basis for subsequent research to validate the findings through a questionnaire survey, *on-site* environmental monitoring, thermal imaging and secondary data collection of household energy bills. It enables the provision of an exemplar base-case scenario development for the building energy simulations in terms of the complex intrinsic interrelationships that exist among the socio-technical influences on household energy consumption.

- The model developed within this empirical study could be used to simulate and predict the dominant representative occupancy energy consumption profiles of the Cypriot households in line with the socio-technical-systems (STS) approach adopted across 36 RTBs in a post-war social housing estate during the hottest summer month of August.

- The developed model can provide a clear understanding of household energy consumption and of the significant impact of both the thermal properties of buildings and the environmental conditions monitored on the development of 'neutral' adaptive thermal comfort. This can serve as a decision-making policy tool capable of directing policy decisions by testing the effects that different policy scenarios, such as energy efficiency improvements and behavioural changes, are likely to have on household energy consumption. The insights generated in the tradition of the socio-technical-systems (STS) approach, adopted through a longitudinal thermal comfort survey of households, can allow policymakers to make informed decisions about future policy formulations on energy consumption reduction in the EU-27 countries.

- The developed model is also capable of modelling and exploring potential retrofit interventions with which the energy consumption reduction targets are being achieved within the South-eastern Mediterranean climate.

- The analysis of the empirical data gathered in case study apartment units, during a series of controlled and uncontrolled experimental conditions, would help determine the extent to which the Predicted Mean Vote (PMV) index is suitable for optimising the respondents' thermal sensations in each occupied space in the summer period – which has shown the regression forecasting of adaptive thermal comfort in Cyprus.

- With respect to analysing the occupants' optimum thermal comfort level, the findings could suggest that the current PMV index was accurate enough while it assessed the dependent variables in the regression coefficient which was generated thorough analysis between environmental conditions and subject respondents' votes on the PMV and, hence, that it requires minor or no correction. This could imply that linear regression lines are capable of demonstrating a suitable benchmark criterion in conjunction with predicting the thermal comfort requirements and, consequently, the energy demand in base-case representative apartment units.

- This empirical analysis reveals that the PMV underestimates the respondents' thermal sensations by conducting one point in time measurements to assess the occupants' thermal comfort thoroughly during the hottest summer month of August. This implies that domestic thermal comfort can be achieved at indoor temperatures higher than those predicted by the PMV.
- The greatest strength stems from the fact that the PMV is shown to overestimate the respondents' thermal comfort preferences while taking into consideration the environmental parameters both the *in-situ* measured and *on-site* recorded at the time the survey was conducted in this Mediterranean climate. This would imply that respondents prefer to keep their indoor

occupied spaces cooler than predicted in order to achieve optimum thermal comfort. This could result in major implications for future energy demand scenarios in the residential sector. Therefore, it can be assumed that the respondents may be more tolerant towards summertime overheating, resulting in a reduction in cooling energy demand.

- A major contribution of this research would be the development and successful testing of comprehensive method of design for assessing domestic energy use and conducting dynamic thermal simulations in representative archetype housing typology. The first two (questionnaire survey and *on-site* environmental monitoring) can be used in future research work to assess building performance evaluations that involve the collection of high-quality empirical data in residential buildings with monitored environmental conditions. At the same time, the third method set (building energy simulation) involves a novel energy calibration approach for validating various variables interrelated with the socio-demographic characteristics of households in the base-case representative apartment units selected for the longitudinal field study. This method could be particularly useful whilst undertaking regression forecasting of 'adaptive' thermal comfort. In fact, it should be indicated that the opportunities, challenges and constraints of the methods identified during the course of this research could be extended to effectively modify them for future use in building performance evaluation and optimisation, thereby assisting in the collection of more empirical data on optimising occupants' thermal comfort.

1.5 State-of-the-art review in retrofit policy design

The introductory Chapter One explicitly provides a foundational definition to explain the background work for the development of STS conceptual framework in the field of applied sciences. It introduces the rationale behind selecting the issue of domestic energy use in corroborating with the occupants' thermal comfort by describing and explaining the main philosophical and theoretical approaches developed through quantitative analytical energy modelling and simulation of energy user profiles. It explains reasons for considering the selection criteria of archetype housing typology for the building energy simulations as a base-case scenario. It describes the methodological workflow of how to conduct a field survey and developing a novel energy calibration model to undertake DTS while considering households' socio-demographic characteristics in energy policy. This chapter also examines the ongoing policy initiatives, schemes, directives and targets that were initiated by the authorities in EU-27 countries to reduce energy consumption in residential buildings, especially in the post-war social housing stock built in the 1980s and early 1990s. The research propositions indicate the applicability of the research to contribute to ongoing studies on overheating and to provide a new form of knowledge to the field of thermal comfort by taking into consideration the occupants' socio-demographic characteristics and environmental conditions in the context of South-eastern Mediterranean climate where the weather is subtropical (*Csa*) and partly semi-arid (*Bsh*).

This chapter also explains the main purpose and objectives of this empirical study. The main research questions and hypothesis are highlighted to provide a clear direction for the development of evidence-based energy-policy framework to assess robust energy performance evaluation and certification schemes in the South-eastern Mediterranean countries. The research methodology is clearly presented and the steps taken to carry out the research are outlined, including in-depth information on the selection criteria of post-war social housing stock, population and location of case study buildings investigated through a questionnaire survey. It presents the outline of data analysis and discussion within a sequentially developed methodological workflow to demonstrate the importance of the novel epistemological research design approach developed for evaluating the energy performance of buildings in the residential sector. The chapter also provides a clear focus of the research and presents the importance of this research to the field of thermal comfort and assessing domestic energy use. Furthermore, it outlines the structure of this research study as well as its contributions and value.

Following a literature review of the state-of-the-art in the area of overheating risk assessment, thermal comfort and upgrading the energy efficiency of buildings in Sections 1.1., the key aims of the study and the corresponding research design to address them are presented in Section 1.2.1. The corresponding methodologies are explicitly mentioned in section 1.3. In this handbook, the data analysis and discussions are divided into five main chapters, with the results for each section presented immediately following the respective methodology. Additionally, the chapter on the limitations of the study is designed to highlight the importance of the technical challenges experienced while conducting the questionnaire survey, recruiting the environmental monitoring campaign and running dynamic thermal simulations while developing a novel methodological framework for the optimisation of post-war social housing developments in the South-eastern Mediterranean climate. A single discussion chapter is included at the end, where conclusions and future recommendations are also explained. The sequential order of the main chapters of this handbook and a description of its content are explained in Section 1.6.

1.6 Content

This handbook comprises 12 interrelated chapters, each forming a coherent case for the research and providing a critical appraisal of the results that follow. Following the introductory Chapter 1, the remaining chapters of the book are presented as follows: literature review (Chapters 2 and 3), methodology (Chapter 4), data analysis and discussion—questionnaire survey, thermal comfort survey, environmental monitoring (Chapters 5, 6 and 7), defining representative building energy models and the calibration process (Chapter 8), building performance evaluation (Chapter 9) and a description of the project limitations (Chapter 10). The results are then analysed and discussed (Chapter 11) and a conclusion is given by reflecting on the study's value for practice, including its anticipated research outcomes and contribution to knowledge (Chapter 12). Finally, recommendations for further research are provided, based on the base-case scenario of this study, for the nationally representativeness of housing stock in both Cyprus and other European countries that have similar climate characteristics and building regulations. The logical structure of how this empirical study is disseminated is shown in Figure 1.7 (a) through (c).

Chapter 1: Introduction

This chapter outlines the knowledge gap in energy-efficiency and retrofitting studies across the EU in an effort to provide a comprehensive understanding of economically viable EPBD implementation schemes and of the efficacy of energy-efficiency upgrades of existing housing stock. This study—on assessing domestic energy use and the occupants' thermal comfort—aims to fill this gap in retrofit policy design. It applies a novel methodological approach to evaluate the building energy performance of base-case representative archetype residential buildings in the South-eastern Mediterranean climate of Cyprus.

Chapter 2: State-of-the-art I: Energy efficiency directives and policy aspirations in retrofit interventions

This chapter introduces the political, economic and social context of Cyprus to provide information about how its political agenda has accelerated changes in energy use by taking into account the detrimental effects of climate change. It discusses the evolution of post-war housing estates and its effects on the environment through the physical characteristics of the high-rise residential tower blocks. The chapter also explains the reason for the growing energy use demand in recent years in Cyprus and across the South-eastern Mediterranean basin.

This chapter also summarises the policy aspirations and provides a roadmap for energy consumption reduction by 2050 with nearly zero carbon buildings in Cyprus, including energy policy aspirations, which motivated the development of building regulations by 2030, are also discussed. This chapter elaborates on the findings of other researchers to provide a background for the development of a novel STS conceptual framework, identify the gaps in previous research undertakings and to elaborate on the chosen approach. It outlines the context and goals of this research project. It illustrates fundamental facts and illustrations that set the context for the study. It also explains the reason for the growing demand for high density residential buildings in recent decades globally.

Chapter 3: State-of-the-art II: Systematic literature review of retrofitting high density residential buildings

This chapter primarily provides a literature review of studies on thermal comfort and retrofit of post-war social housing estates Cyprus and other EU-27 countries. It also outlines, in-depth, a literature study on energy efficiency and retrofit initiatives in Europe and its impact on or implications in Cyprus. The chapter investigates the discourse on EU-27 energy efficiency objectives and the various theories advanced to implement them in current construction practices. It identifies, in detail, a methodological framework to assess the overheating risk in residential buildings and its significant impact on energy use. It also illustrates the requirement of the Energy Performance of Buildings Directives (EPBD) implementation process in terms of investigating into energy efficient technologies for retrofitting high density residential buildings in Europe.

Chapter 4: Methods and Tools:

This chapter presents the methodology by explaining the rationale of the research hypotheses, aims and objectives. It illustrates the case study and explains the research design model adopted to develop the STS conceptual framework in the field of applied energy. It also explains the selection criteria of base-case representative residential tower blocks (RTBs) and presents the data collection methods used, the filed work procedures and the data analysis and interpretation. It fully explains the mixed methods research design approach through a novel methodological framework developed for policy design and retrofitting strategies.

Chapter 5: Questionnaire survey: The significance of occupancy patterns and household habitual adaptive behaviour on home energy performance

This chapter focuses on reporting the collated data together with their analysis and interpretation. The findings are presented in sequential order based on the order in which the questions were asked to the household members. First, descriptive data for each different orientation (northeast, northwest, southeast, southwest and south) and floor level of the interviewed flats are discussed. This is followed by statistical testing using Pearson's rank correlation test to analyse the relationships of the selected questions related to the research questions. The first phase of the survey aimed to understand the age, gender, occupation, ethnicity, socio-demographic characteristics, energy use and thermal comfort preferences of the respondents interviewed in flats from 36 RTBs in the social housing estate.

Chapter 6: Thermal comfort survey II: A field study investigation to assess on households' thermal discomfort and overheating risk of European buildings

This chapter presents the results of the overheating risk assessment of the interviewed flats, as well as the outcomes from *on-site* environmental monitoring, *in-situ* measurements and the thermal comfort surveys carried out in the hottest summer month of 2018—August—with households in the RTBs. The outcomes of the occupants' feelings, either hot or cold, their thermal satisfaction and overall comfort in the winter and summer periods are examined. Additionally, the results of the occupants' current thermal preferences are investigated with concurrent *in-situ* measurements for bringing more reliable information about households' thermal preference levels during the questionnaire survey conducted.

Chapter 7: Thermal Comfort Survey II: A field study investigation on the regression forecasting of neutral adaptive thermal comfort

This chapter primarily focuses on linking all the results from both the general survey and thermal comfort survey findings, *on-site* environmental monitoring, *in-situ* measurements, as well as findings from the overheating analysis, to understand the current energy performance of the flats and the thermal comfort of their occupants. The outcome of the environmental monitoring carried out at the post-war social housing estate during the summer is presented. The variables measured during the survey are discussed in order to understand the environmental conditions of measured flats for assessing their occupants' thermal comfort level and risk of overheating experienced in the summer.

Chapter 8: Energy Calibration: Developing a novel methodology to calibrate building energy performance of social housing estates – Building diagnostics, energy audit and energy forecasting

This chapter considers building energy modelling and dynamic thermal simulations by using the Integrated Environmental Solutions (IES) software suite to further examine the potential of summertime overheating in the post-war social housing estate. Here, the simulations and calibration studies are investigated according to the recommended international benchmarks and criteria for assessing overheating and the occupants' thermal comfort by taking the occupants' real-life experiences with energy use into consideration. For the calibration analysis, the south-facing RTB is chosen as the base-case representative building in order to investigate the existing energy performance of representative flat units for further energy simulations. Hence, the worst-performing representative flat units are considered as baseline scenario development and emphasis is given to the peak cooling period of August to conduct dynamic thermal simulations simultaneously.

Additionally, this chapter demonstrates the findings through a thermal imaging survey conducted in the winter prior to the in-depth questionnaire survey and *on-site* environmental monitoring performed in the summer. It consists of a collection of both walk-through and walk-in information from the thermal imaging survey in order to demonstrate the importance of the impact of building-fabric thermal performance on the occupants' thermal comfort. These results are also validated using the SunCast application of the IES software suite, aiming at analysing the importance of solar irradiance factor onto building envelopes while assessing overheating risk of European buildings.

Chapter 9: Building Performance Evaluation: A novel methodological framework for building optimisation of social housing estates – Policy design and life-cycle cost impact analysis of retrofit strategies

This chapter examines the significance of the orientation of the base-case representative building and its impact on the energy performance of the flats, while also taking floor level differences into consideration. The aim of this section is to investigate the risk of overheating experienced in each occupied space in the representative flats. It seeks to identify the optimal energy retrofitting strategy. For that reason, a holistic retrofitting scenario is considered, which includes the reduced energy consumption, the overheating risk, the energy use behavioural changes of households and the thermal comfort indexing, along with sustainability concerns incorporating the building's geometry and envelope construction while considering various uncertainty parameters between the actual and predicted energy use. The findings are validated by simulation results, *on-site* environmental monitoring and *in-situ* measurements analyses to bring more reliable subsequent information for energy policy design in high density residential buildings.

This chapter also considers an original methodology that employs the adaptive thermal comfort of the guidelines presented in the Chartered Institution of Building Services Engineers' (CIBSE) *Technical Memorandum 52: The Limits of Thermal Comfort—Avoiding Overheating in European Buildings* to predict the energy behaviour of all representative sample flats in the RTBs. The degree of overheating for each occupied space is discussed and evaluated in terms of impact of orientations and floor level differences. The energy performance of buildings is then calibrated by running dynamic thermal simulations aimed at developing a reliable assessment of the overall energy end-uses for space conditioning as well as for optimising the occupants' thermal comfort.

Chapter 10: Limitations: Developing an evidence-based energy policy framework to asset robust energy performance evaluation and certification schemes

This chapter explains the methodology developed and presents some limitations that result from the design of questionnaire survey, population sample recruiting procedure, the response rate of participants targeted, the constrains of *on-site* environmental monitoring and the discrepancies detected between the actual and predicted energy use for validating survey findings. It also discusses the uncertainties and inaccuracies that quantitative modelling adopted for the calibration of dynamic thermal simulation findings in conjunction with the occupants' socio-demographic characteristics, occupancy patterns, household size and environmental parameters both *on-site* measured and *in-situ* recorded.

Chapter 11: Interpretations and discussions: Retrofitting of the post-war social housing estates in the South-eastern Mediterranean climate

A discussion of the five previous chapters—5, 6, 7, 8 and 9—constitutes this chapter in which meaningful comparisons are drawn between the findings from comprehensive methodological approaches developed in the tradition of the socio-technical systems (STS) in energy modelling for concurrently assessing domestic energy use and the occupants' thermal comfort. It presents the highlights of the base-case scenario development to uptake delivery of retrofitting high density residential buildings. It describes the *on-site* environmental monitoring study and shows the assessment of assumptions about the standardised thermal comfort conditions developed for this research context in particular, considering both energy simulations and environmental monitoring studies. This chapter also discusses the findings of the study, including the best optimised energy design parameters found in the prototype RTB and the optimisation of the occupants' thermal comfort as a consideration in the implementation of retrofit strategies for policymaking.

Chapter 12: Conclusions and recommendations: Roadmap to retrofit policy design

This chapter articulates the concluding remarks of the handbook, outlining the limitations and identifying key subject areas for further research.

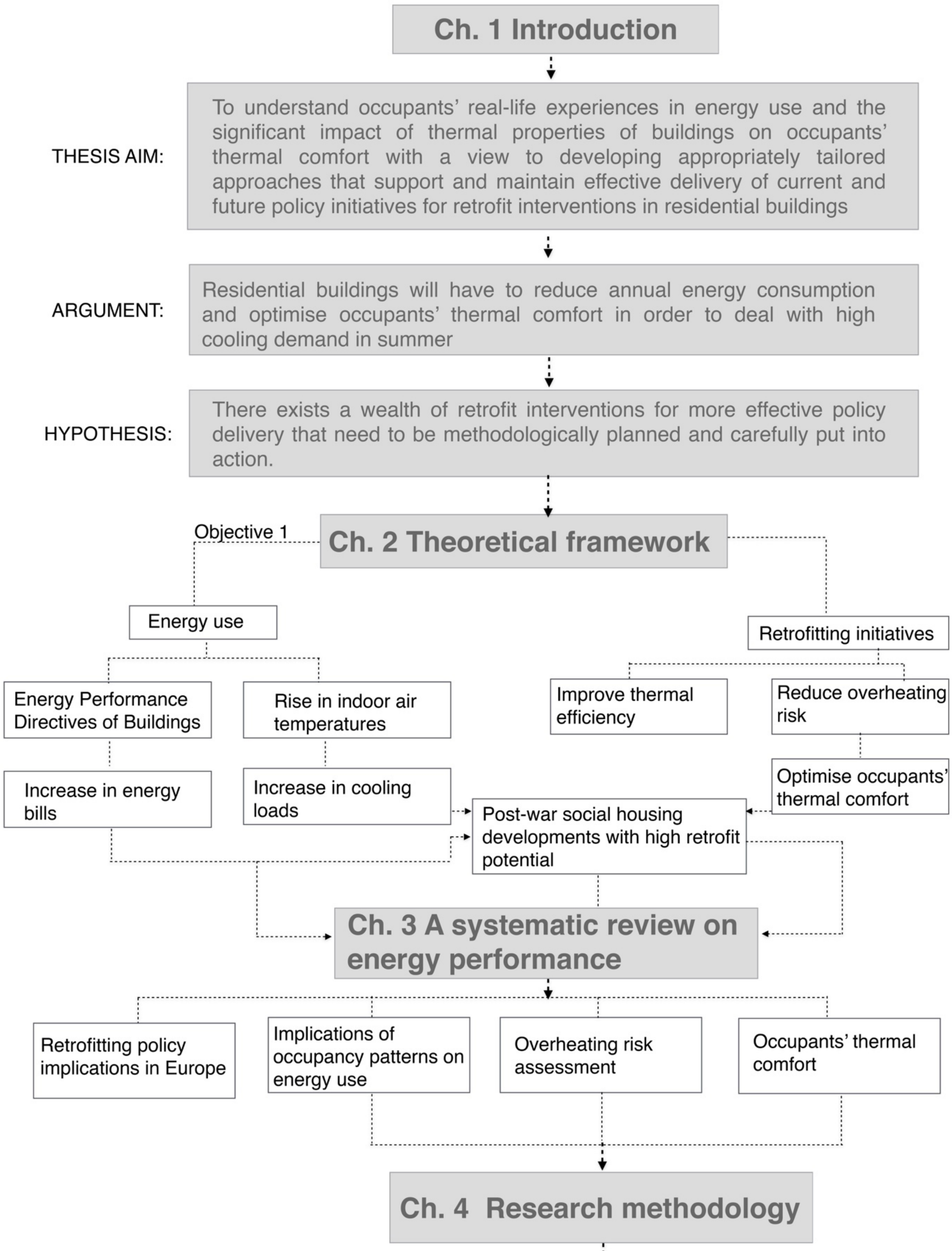

Figure 1.7 (a). The handbook structure and methodology flow diagram: Chapters 1–4.

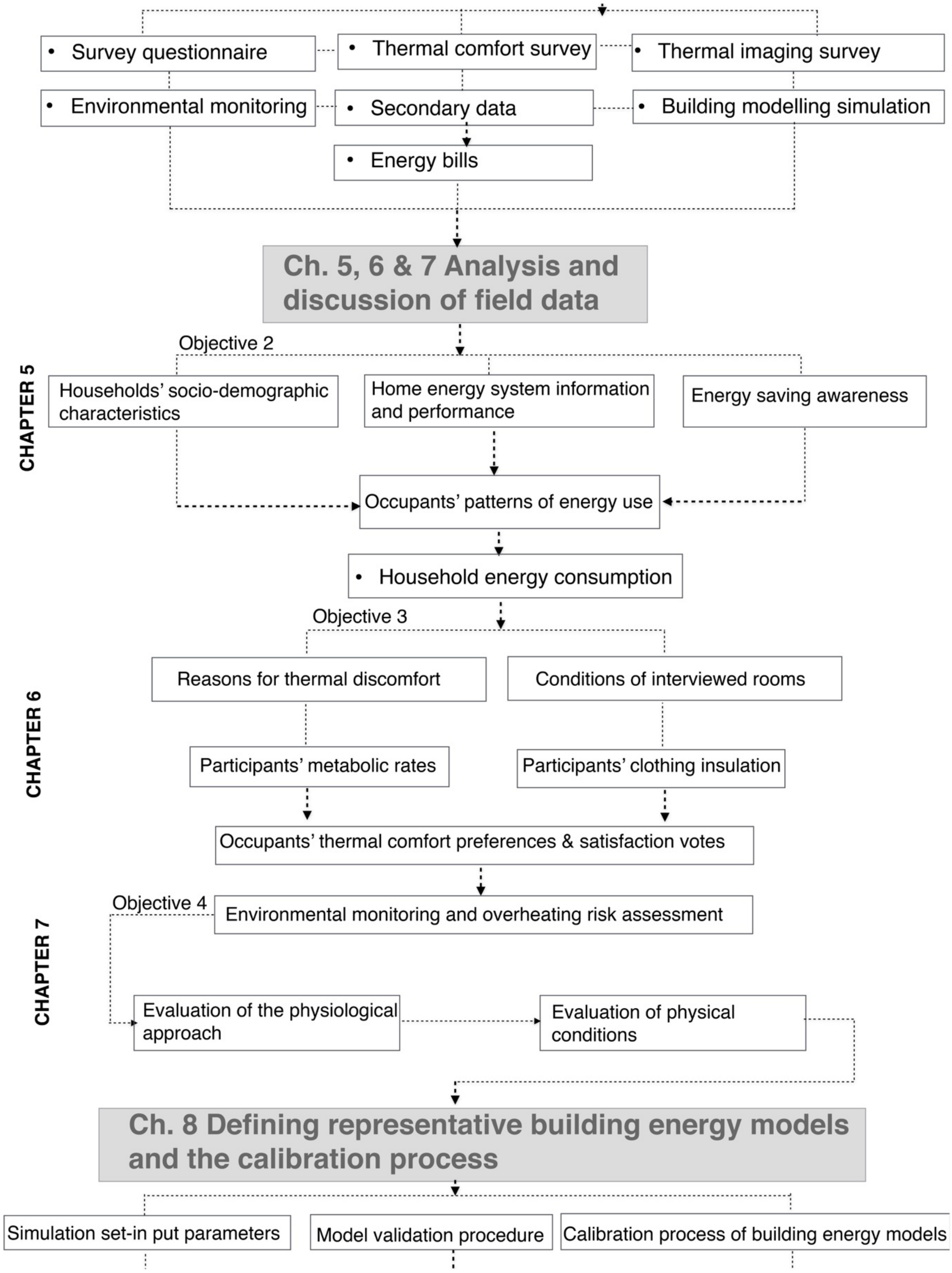

Figure 1.7 (b). The handbook structure and methodology flow diagram: Chapters 4–8.

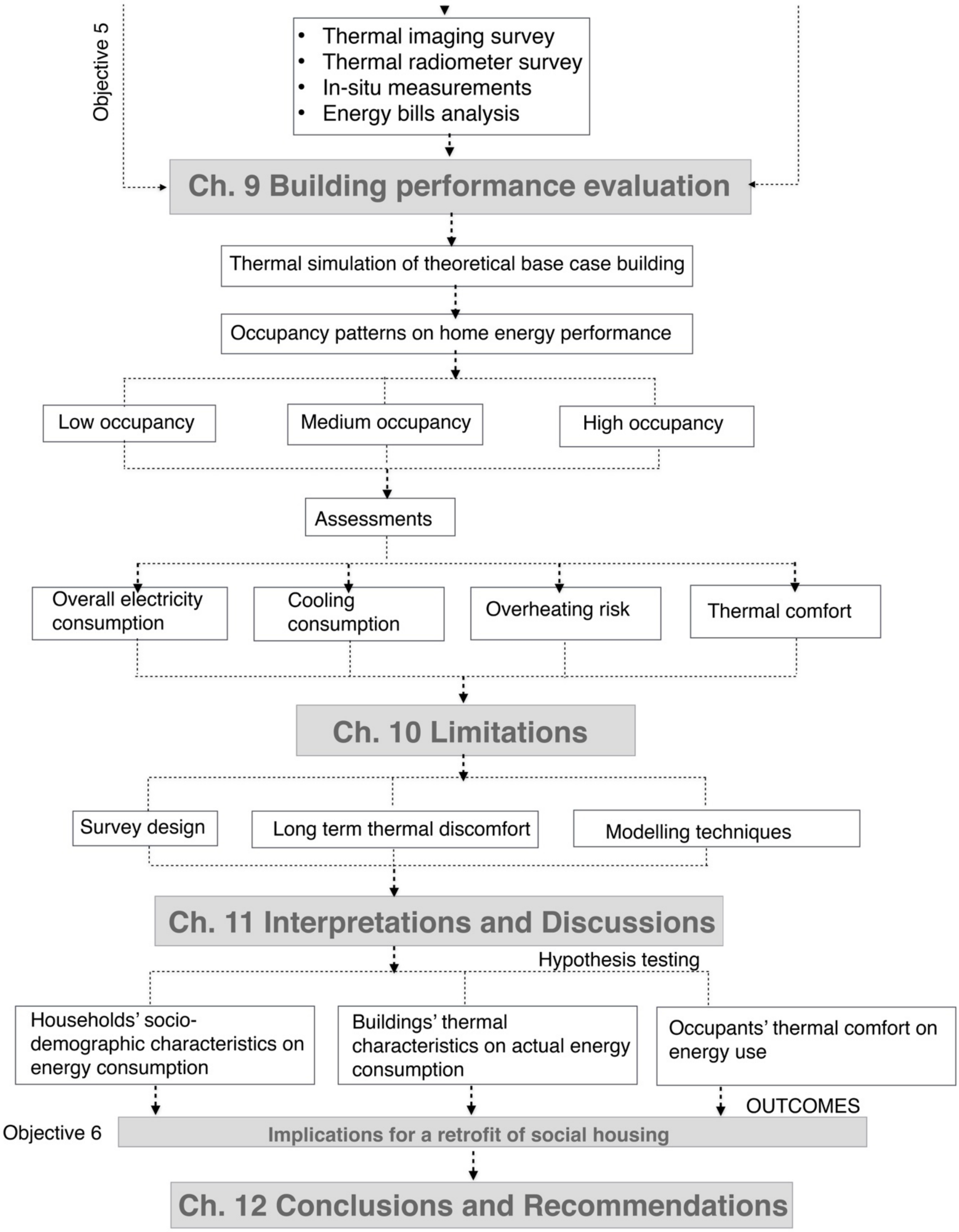

Figure 1.7 (c). The handbook structure and methodology flow diagram: Chapters 8–12.

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